

THE GYRO-PILOT

"What riles me most on deck is them smart quarter-master blokes. You'd think the hooker would go without they turned the spokes. But listen here! A tiffy has invented something new—A ship what steers its blooming self and don't require a crew!"

—*Nautical Magazine*

THE Gyro-Pilot is an accessory to the Gyro-Compass in the same sense that the course recorder and the repeater compasses are accessories. Although it does require the supervision of an officer, just as ships still require crews, its functions are so important from the standpoint of economy and safety that a complete description of it will be given.

Development

As a result of the electrical repeater system, the True North indication of the Gyro-Compass is made available at any part of the ship by means of the positive operation of repeater motors. This availability of an unvarying reference point led to its adaptation as a means of controlling the steering of the ship. As the wheelsman watches the lubber line swing with the ship's head from side to side, he applies corrective rudder to maintain the lubber line as closely as possible to the course he has been told to steer. The wheelsman in this case is a "human repeater", wherein he notices the position of the lubber line and translates that knowledge into corrective action of the rudder. Thus, in order to substitute a mechanical apparatus for the human wheelsman, that apparatus must have a "brain" for detecting the swing of the lubber line from the true Gyro course, and "muscles" which are controlled by this "brain", and which will apply corrective rudder movement.

The Sperry ship Gyro-Pilot is just such an instrument. A repeater motor, mounted inside the housing, positions a pair of contact rollers at all times according to the heading of the Gyro-Compass with respect to a reference point on the ship. This reference point in turn is adjusted by hand

to correspond to the course it is desired to steer. As the ship swings to right or left of this course, the contact rollers will move with respect to the reference point in the same manner as the lubber line moves with respect to the Compass card. This causes a contact to be made which will operate the "muscles" or steering gear control motor, which in turn causes corrective rudder to be applied. When the ship swings back toward the allotted course, the amount of corrective rudder is diminished until the ship is again on her course, at which time the rudder is amidship. The diminishing of the rudder angle and final return to amidships is accomplished by an electrical "repeat-back" system.

The first Gyro-Pilot, installed in the tanker *J. A. Moffat* in 1922 was a very crude apparatus, its component parts being connected in a makeshift arrangement where they would interfere as little as possible with the ship's regular steering equipment. The results obtained on the first voyage were not sensational, but they did show that the principle of automatic steering when used in conjunction with the Gyro-Compass was sound. From the experience gained with this first experimental equipment many improvements were made, and as a result a practical commercial Gyro-Pilot was developed.

In most large vessels the steering wheel operates a hydraulic telemotor which opens or closes the valves of the steering engine to move the rudder one way or the other. The early "single unit" Gyro-Pilots were almost always installed in the wheelhouse, where they operated the ship's steering wheel through a chain drive. They were compact, relatively inexpensive and efficient, but they had one serious drawback: their perform-

ance could be measured roughly by the condition of the ship's hydraulic telemotor. If a telemotor develops leaks or if air is present in the system, its operation is uneven and a certain amount of lost motion is inevitable. Naturally, under such conditions the Gyro-Pilot is at the same disadvantage as the human helmsman, and even though the machine is capable of more accurate steering, the effect of its superiority is lost before it reaches the rudder.

In order to overcome this disadvantage a new type of Gyro-Pilot was developed. Instead of operating through the ship's telemotor, it provides a complete electric telemotor system entirely independent of the ship's existing telemotor. The Gyro-Pilot binnacle containing the control mechanism is placed in the wheelhouse as before, but the drive motor, which formerly was connected by a chain to the ship's wheel, has been taken out of the binnacle and placed in the steering engine room, where it operates the steering engine valves directly. The accurate control signals of the Gyro-Pilot can therefore be applied to energize the rudder without lost motion or other varying factors resulting from imperfect hydraulic telemotor operation.

The Gyro-Pilot control system as originally devised was sufficiently accurate to meet the requirements of all commercial service. For the steering of the high speed express liners which have been built more recently, however, it was apparent that more sensitive control of the rudder was required. The inertia of the drive motor of the Gyro-Pilot was such that with the existing control arrangement it could not be stopped and started quickly enough to secure the desired results. The sensitivity of the Gyro-Pilot was limited to about $\frac{1}{2}$ a degree: that is, the ship might yaw from $\frac{1}{3}$ to $\frac{1}{2}$ degree before the motion could be picked up and applied to the rudder. The entire control system of the Gyro-Pilot was redesigned, therefore, with the result that it will now apply corrective rudder for one-sixth of a degree departure from the course. Its sensitivity is more than sufficient to meet the steering requirements of all classes of vessels.

DESCRIPTION

The Gyro-Pilot equipment consists of a control unit, a power unit, a motor control panel and a dynamotor. The control unit contains the signal and control circuits for operating the power unit. The power unit contains the drive-motor and gearing necessary for moving the steering engine valve gear. The motor control panel contains the relays for amplifying the relatively small control currents into currents of sufficient strength to actuate the drive motor of the power unit. The dynamotor changes the ship's D-C supply into 115 volt, 60 cycle alternating current for operating the A-C relays and the self-synchronous repeat back system which cuts off the control signal. An equipment arrangement is shown in Figure 34.

Control Unit

The control unit or binnacle of the Gyro-Pilot is mounted in the wheelhouse and contains the mechanism and the electrical circuits for controlling the rudder automatically through the Gyro-Compass repeater system, or manually by means of the pilot wheel. It also contains the weather and rudder adjustments for use with automatic steering. On the top of the control unit is a swivel yoke in which the steering repeater is supported. The control unit is shown in Figure 35. Its details are as follows:

Control Lever: The control lever on the side of the Gyro-Pilot binnacle enables the operator to select the form of steering he desires. The control lever has three positions: "Off", "Hand", and "Gyro". Moving the control lever to the "Off" position opens a control switch in the control unit binnacle, disengaging a magnetic clutch on the power unit and permitting the rudder to be controlled through the ship's hydraulic telemotor system by means of the telemotor wheel. Moving the control lever to the "Hand" position closes the control switch in the binnacle and engages the magnetic clutch on the power unit. Hand-electric, follow-up steering is now available under control of the pilot wheel. With the control lever in the "Gyro" position, the ship is kept on her course automatically under control of the Gyro-Compass.

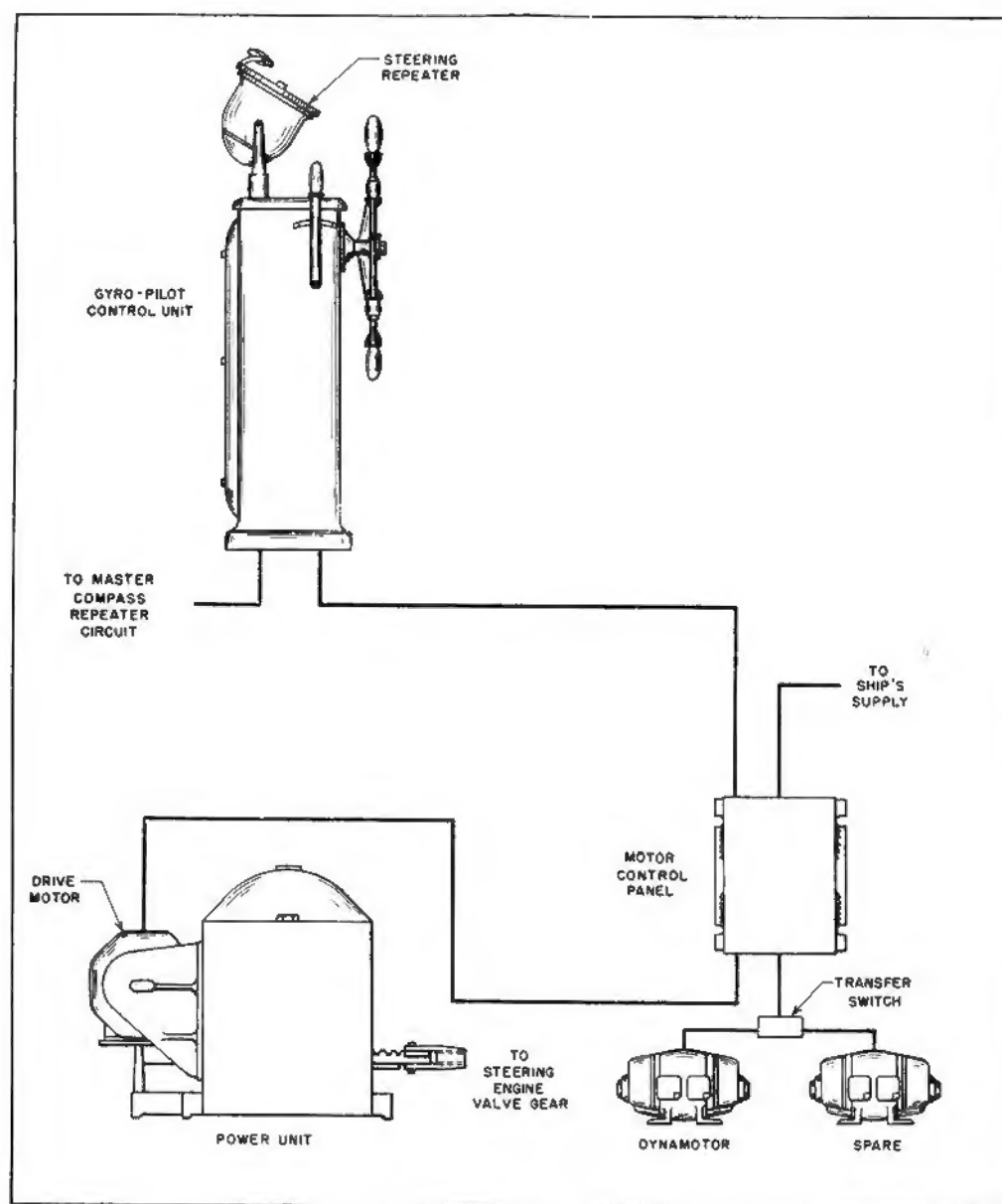


FIGURE 34.

Gyro-Pilot arrangement.

Repeater Motor: The repeater motor within the control unit binnacle is connected to the Master Compass and drives the inner member or trolley of the contact ring assembly.

Contact Ring Assembly: The outer member of this assembly consists of two current-carrying rings concentrically mounted. Each ring is composed of two semi-circular segments separated by air gaps. The inner member or trolley assembly

consists of two energized rollers, one of which rests upon the outer concentric ring, the other upon the inner. Both of these rollers are connected to one side of the armature circuit of the servo motor. The electrical arrangement is such that when the circuit is completed through the outer ring, the servo motor is driven in one direction; when the circuit is completed through the inner ring, it is driven in the opposite direction.

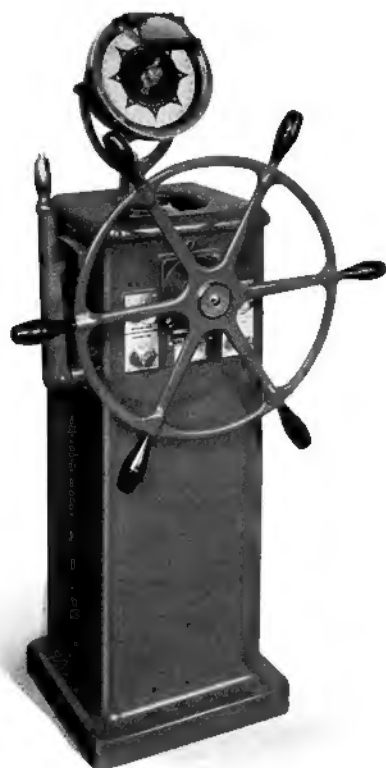


FIGURE 35.

Gyro-Pilot control unit.

The pointer on the gyro-pilot steering repeater provides a large and easily discernible steering reference.

Servo Motor: The servo motor is geared to the contact rings so that rotation of the motor causes the rings to follow the movement of the trolleys and stop the motor. The servo motor also drives, through a differential gear, the control ring assembly which actuates the power unit drive-motor.

Control Ring Assembly: This assembly is similar in construction to the contact ring assembly, but its trolleys normally rest upon the dead segments of the concentric rings instead of the live segments. The concentric rings are driven either by the servo motor or by the pilot wheel (depending upon the position of the control lever) and an electrical circuit is completed through the current-carrying segments and the trolleys to operate the A-C. relays on the motor control panel. These relays in turn operate the clapper switches which control the drive-motor. Follow-up control is ob-

tained through the trolleys in the control ring assembly, which are geared to the self-synchronous receiver.

Pilot Wheel: The pilot wheel operates the outer member of the control ring assembly through a differential gear. This gear also serves to prevent the servo motor from revolving during pilot wheel steering. A friction brake on the pilot wheel shaft prevents the pilot wheel from turning during automatic steering.

Position Indicator: The steering wheel position indicator on the top of the Gyro-Pilot binnacle is geared to the contact rings of the control ring assembly. Its pointer moves over a graduated dial which is illuminated at night by means of a dimmer light mounted on the binnacle. The position of the pointer indicates to the wheelsman the position of the pilot wheel relative to the amidship position.

The Power Unit

The power unit, Figure 36, contains the necessary equipment to operate the steering engine valve. This is accomplished by the drive motor through the magnetic clutch and gear train. A push rod with removable pin couplings connects the power unit rack to the valve gear. The power unit also contains a rudder limit switch and the

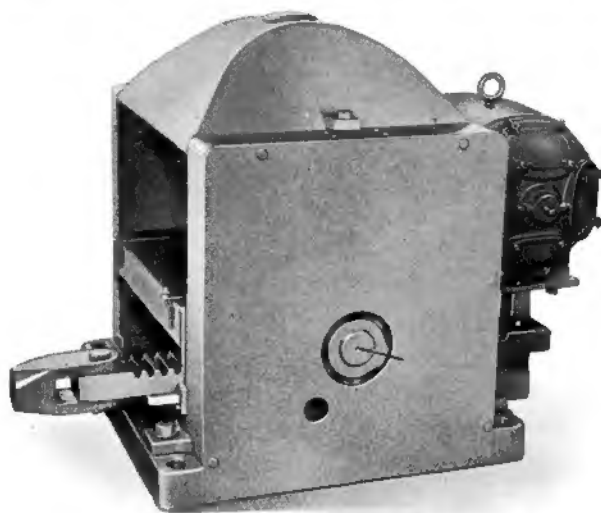


FIGURE 36.

The power unit.

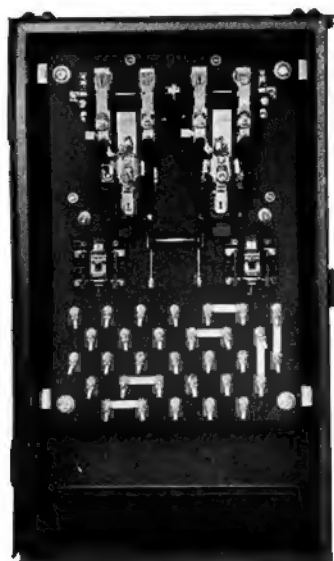


FIGURE 37.
The motor control panel.

self-synchronous transmitter which is part of the follow-up system. A description of the principal parts of the power unit follows:

Drive Motor: This motor is a compound-wound interpole motor. It is designed for severe dynamic braking to insure the quick stopping which is essential for accurate control of the rudder.

Magnetic Clutch: The magnetic clutch disconnects the drive-motor and its gearing from the rack and pinion gears controlling the steering engine valve. The clutch releases instantly upon failure of current or when the control lever on the Gyro-Pilot binnacle is moved to the "Off" position.

Rudder Limit Switch: A cam-type limit switch on the power unit prevents moving the rudder more than a predetermined angle on each side of the mid-ship position. The cam roller opens the switch arm and interrupts the operating circuit on the side engaged, but does not prevent the rudder from being moved back toward center. The cams are operated by a gear mechanism attached to the driving gears, and are thus in permanent agreement with the rudder. The switch arm resets itself after each opening.

Self-Synchronous Transmitter: This unit is geared to the rack and pinion drive and causes the self-synchronous receiver in the control unit binnacle to duplicate its every movement. The trolleys of the control ring assembly are driven by this receiver and caused to follow the movement of the outer member, thus opening the circuit to the drive-motor.

The Motor Control Panel

The motor control panel, Figure 37, contains the electrical circuits and the switches necessary to control the drive motor in the power unit. The purpose of the D-C. supply switch is to connect the ship's D-C. supply to the panel. The two A-C. pilot relays control the two clapper switches, thereby closing the circuit to the drive-motor and causing it to run in one direction or the other. The armature of each of the clapper switches is fitted with a dynamic brake contact. The armatures are pivoted so that when one of the clapper switches drops out, due to the opening of the control circuit, the corresponding dynamic brake contact is closed, preventing the drive motor of the power unit from imparting further motion to the steering engine valve.

Dynamotor

This machine converts the ship's D-C. supply into 110-volt, 60 cycle, alternating current for operating the self-synchronous repeat back system and the pilot relays.



FIGURE 38.
The dynamotor.

OPERATING PRINCIPLES OF THE GYRO-PILOT

Automatic Steering

The Master Gyro-Compass establishes a reference line with respect to the earth's surface so accurate and so stable that even the slightest yawing of the ship is indicated simultaneously by a relative movement of the repeaters. The function of the Gyro-Pilot in automatic steering is to pick up this relative movement and convert it into corrective application of the rudder. Reference should be made to Figures 39 and 40 when reading the following paragraphs. Figure 39 shows the mechanical arrangement of the Gyro-Pilot; Figure 40 shows the electrical connections schematically, with the follow-up ring assemblies in simplified form for clarity.

Signal Circuit: The repeater motor within the Gyro-Pilot control unit initiates the signal for corrective rudder. The operating cycle of the signal circuit is as follows: when the ship is on its course the actuating trolleys of the contact ring assembly are in a neutral position, as shown in Figure 39, making contact with both of the energized segments SA_1 and SA_2 of the contact rings, shorting the armature and locking the servo motor due to dynamic braking action.

Suppose the ship yaws slightly to the right of the course: the angular motion is instantly picked up by the repeater motor, and the trolley assembly rotates counterclockwise, causing the lower of the two rollers to move to the right a fraction of a degree, so that it no longer touches segment SA_1 of the contact ring assembly. The armature of the servo motor, instead of being shorted out, is now energized through circuit SA_2 . The servo motor starts instantly and through the differential causes the outer member or contact rings of the control ring assembly to rotate in a clockwise direction. The energized segment C_1 therefore, makes contact with the inner member or trolley SS_1 , closing the circuit to the pilot relay A. The operation of the pilot relay closes the drive-motor control relay A. Relay A closes contacts #1 and #2 by means of one of the two clapper switches

and energizes the drive-motor, causing it to turn in the direction to give left rudder.

The movement of the drive-motor rack and pinion operates the self-synchronous transmitter in the power unit which causes corresponding rotation of the self-synchronous receiver in the control unit binnacle. The receiver causes the trolleys SS_1 to follow the movement of the contact rings and open the circuit to the drive-motor. The opening of the clapper switch energizes the down contacts and stops the drive-motor through dynamic braking action.

Figure 39 shows that the servo motor, in addition to driving the outer member of the control ring assembly through the differential, drives the outer member of the signal ring assembly, through the rudder adjustment, causing the outer member to follow the movement of the signal trolley assembly until the lower of the two trolleys again rests upon segment SA_1 . This short-circuits the armature of the servo motor and stops the motor. The signal circuit sequence described in this paragraph functions independently of the control circuit to start and stop the servo motor. Whenever the servo motor is running, however, it actuates the control circuit and therefore operates the drive motor. It will be understood from the foregoing that the function of the signal circuit, including the starting and stopping of the servo motor, is to provide a sensitive and accurate means of energizing the control circuit—the function of the control circuit to provide positive control of the drive-motor.

If the ship yaws to the left instead of to the right, the repeater motor turns in the opposite direction and the upper roller of the signal trolley moves to the right, energizing the servo motor armature circuit through SA_1 . The servo motor now runs in the opposite direction, control circuit C_2 and pilot relay B are energized and right rudder is applied. Again the outer member of the signal ring assembly overtakes the inner member, the signal is cut off, and the servo motor is stopped. When the servo motor stops, the outer member of the control ring assembly stops also, and its trolleys, driven by the self-synchronous

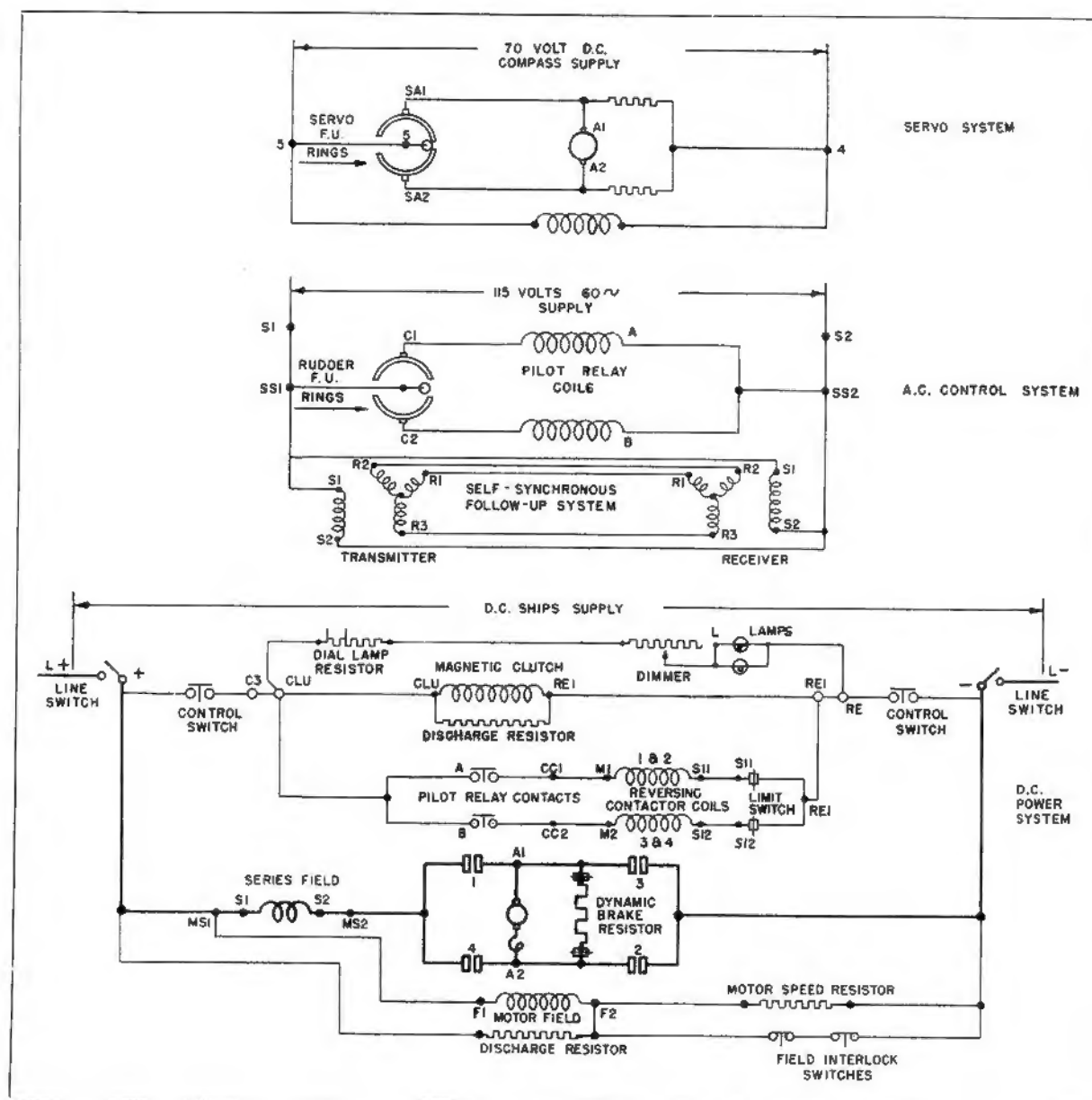


FIGURE 40.

Schematic wiring diagram of the gyro-pilot.

receiver, cross the gap between the segments and open the circuits to the drive motor.

Because of the space required to describe fully the sequence between the original signal and the movement of the drive-motor, the time factor might appear to be considerable. The functions are entirely electrical, however, and therefore the several steps take place practically simultaneously.

There is no discernible interval between the initial signal and the response of the drive-motor.

Weather and Rudder Adjustments

In order that the Gyro-Pilot may be useful under all conditions, facilities are provided in the equipment to take care of the variable factors which influence the steering of the vessel, such as

weather conditions and the characteristics of the ship itself. In rough weather, for instance, it is desirable to let the ship have a small amount of "weather yaw". This is accomplished by means of the weather adjustment. The "rudder" adjustment varies the amount of rudder applied for a given amount of departure from the set course.

The weather and rudder adjustments are shown diagrammatically in Figure 39. The weather adjustment is simply a means of introducing any desired amount of lost motion between the repeater motor and the signal trolley. For example, when set for 1° , the ship can yaw that amount each side of the set course without moving the trolley. When the yaw exceeds the amount for which the weather adjustment is set, the trolley is moved and rudder is applied to correct the deviation from the course.

The weather adjustment is set to zero except in rough weather when it is desirable to allow the ship to respond somewhat to the temporary action of heavy seas. Under such conditions the weather adjustment is opened out as required to prevent racing of the steering engine back and forth.

The rudder adjustment provides a means of controlling the amount of rudder applied for a given departure from the course. The usual position of the rudder adjustment knob is between 0 and 2 for a light ship and between 2 and 4 for a loaded ship. The effect of this adjustment is to delay the follow-up movement of the outer rings until a certain amount of initial rudder movement has taken place. For example, suppose the rudder adjustment is set for 3° . The ship yaws from her course sufficiently to cause the trolley to energize the servo motor. The drive-motor is energized, and the rudder is moved 3° before it is stopped. Thereafter, any further deviation from the course causes the rudder to move in proportion to the degree of deviation. The amount of the initial rudder movement required in either direction depends upon whether the ship is light or loaded. By means of the rudder adjustment this first rudder movement can be made longer than those that follow, the purpose being to

apply sufficient rudder on first making contact to check the ship's angular momentum. If the first movement of the rudder is not sufficient, additional rudder movements are given until the momentum is checked. These succeeding movements, however, are made smaller purposely in order to avoid returning the ship with too much rudder.

Under fairly uniform conditions of sea the initial rudder adjustment can be set so that the first rudder application is sufficient to bring the ship back to her course.

The rudder adjustment also provides the means for "meeting" the ship as she returns to the course. For example, suppose the movement of the ship is checked and she starts returning to the set course. The trolley in the signal ring assembly then makes contact with the opposite segment, thus reversing the servo motor. The drive-motor is started in the opposite direction and continues to run until the servo motor has taken out all of the "plus and minus" set in the rudder adjustment and the follow-up ring has caught up with the trolley. This does not occur until the rudder has moved over to the opposite side, thus "meeting" the ship as she returns to the course.

When the rudder adjustment is properly made, the movement of the ship's head is small and is under the control of several influences such as propellers, slight lateral and longitudinal motions, seaway, wind, and even warping and bending of the ship. Thus, the ship's head often crosses the movement of the rudder and the rudder is restored to a central position with the ship steadied on the course. This condition occurs in automatic steering with about the same frequency as it does with hand steering. The automatic method is more accurate, because it is more sensitive in its response than is a human helmsman and because it permits precise control of initial rudder.

Course Changes: The gearing between the signal and control systems is such that course changes can be made while steering "gyro" simply by turning the pilot wheel in the desired direction.

The rate of the course change can be controlled by turning the Gyro-Pilot steering wheel at a sufficient rate to hold the wheel pointer at the desired angle from its central position. Pilot wheel control is then superimposed upon the signal from the servo motor. The operation of the servo motor is unaffected, and after the ship has attained the new course the Gyro-Pilot will continue to control the rudder automatically. One wheel turn gives a course change of approximately three degrees. If the pilot wheel is turned, for example one full turn, while the control lever is set for "gyro" steering, the rudder will be applied, and as the ship responds, the signal system actuated through the repeater motor, will operate to restore the rudder to the midship position, leaving the ship steadied on a new course which is approximately three degrees at variance with the previous course.

Also for course changes the control lever can be moved to the "hand" position and the rudder applied by turning the pilot wheel as necessary. The repeater motor now is locked and the signal circuit inoperative, so that the rudder, instead of being returned to the midship position, will remain at an angle which is proportional to the angle through which the pilot wheel is turned. Therefore, the ship will continue to turn until the rudder has been restored to the midship position by opposite movement of the pilot wheel.

The rudder order indicator on the top of the control unit binnacle shows the "order" to the rudder. In automatic steering, the order originates in the servo motor. In hand electric steering the order originates in the pilot wheel. The angle through which the rudder has actually been moved is indicated on the ship's rudder angle indicator.

Hand Steering

Moving the control lever from the "gyro" to the "hand" position locks the repeater motor mechanically. The entire signal circuit including the weather and rudder adjustments is now inoperative because with the repeater motor locked there can be no movement of the signal trolleys,



and therefore no movement of the servo motor and the outer rings of the signal ring assembly. The rudder is now controlled by means of the pilot wheel which operates through a differential and train of gears to drive the contact rings of the control ring assembly. When the pilot wheel is turned, the control circuit, through the relays on the motor control panel, actuates the drive-motor in the same manner as it does for automatic steering, the follow-up transmitter and receiver causing the trolleys to follow the contact rings and open the circuit so that rudder application is always proportional to the angle through which the pilot wheel is turned.

Steering With the Ship's Wheel

When the control lever on the Gyro-Pilot is moved to the "off" position, the control switch in the binnacle is opened and the magnetic clutch on the power-unit disengaged. The rudder is controlled through the ship's hydraulic telemotor system by means of the ship's wheel.

Gyro-Pilot Adjustments, Illustrated

In order to illustrate the advantages to be gained from making correct adjustments on the

Gyro-Pilot for existing sea conditions, a sample record is included (Figure 41), together with a brief explanation of the effect of changing the weather and initial rudder adjustments. The record is to be read from the bottom upward in accordance with the hour notations at the left.

It is to be noted that at 10 P.M., with a moderate breeze and an easy beam swell, the adjustments for weather and rudder were set at $\frac{1}{2}$ and $1\frac{1}{2}$ respectively. (The $1\frac{1}{2}$ rudder adjustment resulted in 3° of initial rudder, in this particular installation.) Steering was fair; deviations were within $\pm 1^\circ$. Better steering would have resulted had the weather adjustment been set at 0, a position suited to the mild weather.

At 12:21 A.M. the weather adjustment was set at 0 and the rudder adjustment was varied experimentally between 1 and 3. Steering was poor, due to excessive rudder adjustment.

At 1:26 A.M. the rudder adjustment was returned to $1\frac{1}{2}$, with weather adjustment remaining at 0. Steering was good, deviations being mostly within $\pm 1\frac{1}{2}^\circ$.

Course changes made slightly before and after 12 midnight can be discounted when interpreting this record.

Notations made on the record, of ship designation, weather and sea conditions, speed, roll, weather and rudder adjustments, etc., will be found to add inestimably to the reference value of the document. Such notations should be made on the record by the deck officer at each watch.

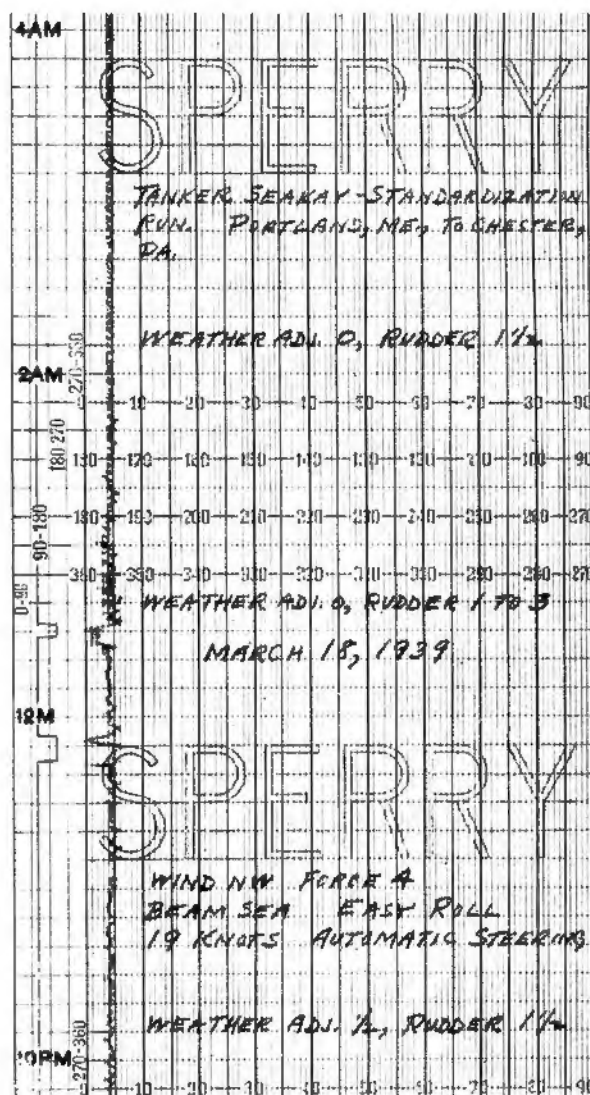


FIGURE 41.

Sample course recorder record, showing effect of adjustments. Read from bottom up.